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SATELLITE REMOTE SENSING OF HEAT STRESS DURING RESERVE TRAINING AT FORT HOOD

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ABSTRACT

Weather effects on soldiers have a profound impact on military operations in climatic extremes. In hot regions, soldier performance limits and drinking water requirements are crucial factors in mission planning and tactical options. The ability to quantify heat stress levels across an entire operational area would provide an information resource for optimizing soldier performance in high mobility AirLand scenarios. Preliminary tests of satellite remote sensing methods currently under development (SBIR contract No. DAMD 17-86-C-6004), were conducted during reserve training operations at Fort Hood, Texas in June 1988. Data were obtained from the AVHRR (Advanced Very High Resolution Radiometer) and TOVS (TIROS Operational Vertical Sounder) instruments aboard NOAA polar orbiting satellites. WBGT (Wet Bulb Globe Temperature) index values derived from satellite data are compared with contemporary surface level measurements and heat casualty rates. Results and salient issues in further development of this capability are described.

1. INTRODUCTION

In hot regions, air temperature, humidity, solar radiation, and wind speed interact to produce a dynamic heat stress environment. When logistically austere conditions and the physically demanding roles of modern combat soldiers are superimposed on that environment, the individual soldier and his mission are threatened by the risk of potentially lethal heat injury.

Strategies to optimize soldier performance and prevent heat injury in military settings are predicated on the availability of quantitative assessments of the prevailing heat stress. At present, the Wet Bulb Globe Temperature (WBGT) index is used to quantify the prevailing local heat stress (TB MED 507, 1980). This simple index integrates the effects of the physiologically relevent meteorological parameters into a single number that is directly related to the severity of the environmental heat stress. Measurements are made typically at hourly intervals and the WBGT index is computed using Eq. 1, where WB is the naturally convected wet bulb temperature, BG is the 15 cm Vernon black globe temperature, and DB is the dry bulb temperature.

$$WBGT = 0.7\ WB + 0.2\ BG + 0.1\ DB \tag{1}$$

The range between 27.8 °C and 32.2 °C on the WBGT index scale includes four heat stress categories, each 1 to 2 °C in width, for which specific military guidelines on hourly water consumption rates and work/rest cycle limits have been established (GTA 8-5-45, 1985). Small changes in the prevailing WBGT can, for example, have a substantial effect on water logistics: across the four categories in that 4.4 °C span, the hourly drinking water requirements quadruple from 0.5 to 2.0 liters per hour per man. The delivery of adequate volumes of drinking water is a critical element in the prevention of heat injury (Hubbard et al., 1982).

As Army doctrine evolves in the direction of increasing tactical mobility, the need for accurate and spatially extensive assessments of heat stress becomes more acute. The exploitation of satellite remote sensing technology to satisfy that need is in consonance with evolving concepts (FM ASI-X1, 1988) and meteorological systems already under development (Brown, 1986).

The US Army Research Institute of Environmental Medicine (USARIEM) is involved in an SBIR contract with Gulf Weather Corporation to develop data processing algorithms which use weather satellite data to quantify heat stress parameters at ground level. This effort employs data obtained from the Advanced Very High Resolution Radiometer (AVHRR) and TIROS Operational Vertical Sounder (TOVS) instruments flown aboard NOAA polar orbiting satellites (Schatzle et al., 1987). The complex influences of local geomorphology and the diurnal heating cycle on the interpretation of sensor output as well as the current limitations in satellite pass frequency pose a significant technical challenge for this application. Nevertheless, the benefits of even a basic capability in this area far outweigh the liabilities of a necessarily complex data processing approach. Although the individual satellite-derived heat stress parameters are, in this report, processed to provide data consistent with existing WBGT based doctrine, they could also serve as inputs to more sophisticated computerized predictive models (Pandolf et al., 1986). Such models, integrated with weather data acquisition, processing, and communications systems, represent the next generation in military heat stress management.

The annual field training exercise of the 44th Evacuation Hospital, 807th Medical Brigade at Fort Hood, Texas in June 1988 presented an opportunity to obtain a preliminary evaluation of the remote sensing capability. As part of a larger study (Rose et al., 1988) of military heat injury prevention issues being conducted with that unit, extensive surface level measurements of prevailing heat stress were made. These 'ground truth' heat stress measurements provided a basis for evaluating the reliability of estimates derived from contemporary satellite passes.

2. OBJECTIVES

There were two primary objectives for this effort: first, document the spatial and temporal variation in point measures of heat stress within an AVHRR pixel size area at Fort Hood and, second, compare the satellite-derived pixel 'values' for heat stress with contemporary measured 'ground truth' values.

3. METHODS

3.1 SURFACE LEVEL MEASUREMENTS

3.1.1 Location

The test location of the 44th Evacuation Hospital at Fort Hood was 31^{o} 15.6' N, 97^{o} 48.2' W and the elevation was approximately 286 m above sea level. The site consisted of generally open, grassy rangeland with a gentle slope (2% grade) downward toward the Southwest.

3.1.2 Weather Measurements

Windspeed and relative humidity levels were continuously recorded at a central site approximately 50 meters from the hospital tents using a battery operated portable weather station (Met One Inc.). Standard WBGT index measurements, using the full size apparatus described in TB MED 507, 1980 and sling psychrometer measurements were made at half-hour intervals throughout the daylight hours. An electronic WBGT data logger (Metrosonics Inc.) provided a record of minute-to-minute changes in WBGT. All measurements were made at a height of 1.2 meters above ground level.

3.1.3 Instrument Deployment

Since a 1.1 x 1.1 km earth surface element, or pixel, represents the spatial limit of resolution for the AVHRR data, an array of six additional WBGT data loggers was deployed within a 1 km^2 area around the central site. These devices recorded the components of the WBGT index, (wet bulb, dry bulb, and black globe temperature) at 1 minute intervals and provided the discrete-point measurement data necessary to compute an average WBGT value and assess the point-to-point variation within a pixel size area at the time of a satellite pass.

3.2 SATELLITE DATA

3.2.1 Data Source

Gulf Weather Corporation was advised of the dates of the Fort Hood study, and was subsequently provided with the exact latitude and longitude of the test site. Gulf then obtained the necessary satellite data tapes from the National Environmental Satellite, Data and Information Service (NESDIS), Washington, DC and proceeded with its satellite data analysis independently: this was a 'blind' test and Gulf had no knowledge of the surface level heat stress measurements made by the USARIEM staff at Fort Hood.

3.2.2 Georeferencing

Because there is some inherent error in the latitude and longitude information embedded in the satellite data, and because the surface data collection was localized within a 1 km^2 area, special efforts were made to accurately identify the appropriate satellite data pixels. Using commercially available software, a subsection of the satellite image was rewarped to visible surface features of precisely known location. From this rectified image, the target pixel containing the 44th Evacuation Hospital location at Fort Hood was identified for each satellite pass.

3.2.3 Dry Bulb and Black Globe Temperatures

Dry bulb and black globe temperatures were estimated from the radiometric measurements provided by the AVHRR instruments aboard NOAA 9 and NOAA 10. Pixel values from the thermal channels were used in conjunction with Planck's Law to compute apparent black body or 'brightness' temperatures. Preliminary algorithms have been developed that relate these 'brightness' temperatures to the dry bulb and black globe temperatures at the surface (Schatzle et al., 1987). In computing the black globe temperature, a constant windspeed of 2 m/s was assumed.

3.2.4 Wet Bulb Temperature

Wet Bulb Temperature was derived using data from the TOVS instrument package aboard the satellites. The TOVS provided estimates of atmospheric water vapor content in three atmospheric layers expressed as depth of precipitable water. A relationship has been developed that relates the total precipitable water in the atmosphere to the wet bulb temperature at the surface (Schatzle et al., 1987). Because the surface resolution of TOVS data is 250 km, an interpolation scheme was employed to estimate values at the target AVHRR pixel.

4. RESULTS

4.1 SURFACE LEVEL HEAT STRESS MEASUREMENTS

4.1.1 Standard Measurements

Table 1 provides a summary of heat stress conditions and their impact for each of the test days, 0800-2000 local time (GMT-5 hr). The WBGT data in Table 1 are based solely on the hourly observations of WBGT at the central site and are therefore consistent with current heat stress measurement practices in the field. It is clear from Table 1 that conditions on 9 June produced the most severe heat stress levels and this is reflected in the hospital admissions for heat casualties. These cases occurred primarily in units that failed to adhere to the appropriate water consumption rate and work/rest cycle limits dictated by the prevailing WBGT.

TABLE 1. HEAT STRESS AT FORT HOOD, 6-13 JUNE, 1988, 0800-2000 LOCAL TIME

Day	Daily Max. WBGT	Total Hours WBGT >27.8°C	Total 12 Hour Water Requirement*	Heat Casualty Admissions
6 June	28.4 °C	1	3.8 liters	0
7	28.8	4	4.4	2
8	29.4	7	5.0	1
9	31.9	10	10.1	13
10	26.1	0	3.6	0
11	25.9	0	3.6	2
12	25.5	0	3.6	0
13	27.6	0	3.6	0

* Based on minimum hourly water consumption rate schedule (GTA 8-5-45, 1985) for WBGT of 27.8 °C (82.0 °F) and above. Constant 0.3 L/hr rate for WBGT less than 27.8 °C was assumed.

4.1.2 Temporal and Spatial Variation in WBGT

The inherent uncertainty in both the temporal and spatial extension of a single 'point' measurement value per hour is a relevant concern for existing doctrine implementation and it impacts upon the interpretation of remote sensed values which are 'area' measurement values at a given instant in time.

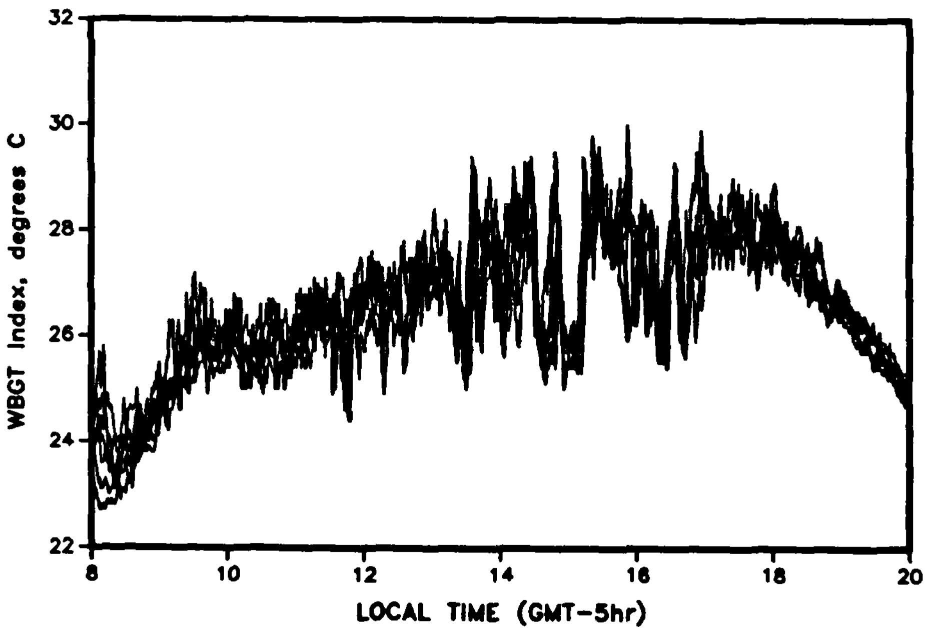

FIGURE 1. One minute interval readings from 7 WBGT loggers deployed within a 1 km^2 area, 44th Evacuation Hospital site at Fort Hood, Texas, 0800-2000 local time on 7 June 1988.

Figure 1 shows a 12 hour segment of the diurnal heat stress profile for 7 June using the 1 minute interval data from the 7 deployed data loggers. This profile illustrates the sensitivity of the WBGT to passing high clouds and short term fluctuations in wind speed. The spatial, or point-to-point, variation in the 7 WBGT readings at a particular minute ranged from ±0.2 °C to ±1.0 °C (1 Standard Deviation of the mean), with a general tendency toward lower spatial variation near sunset. The temporal, or minute-to-minute, variation during 1 hour time periods, consisting of 60 consecutive WBGT readings from a single logger, ranged from ±0.5 °C to ±1.0 °C (1 Standard Deviation of the mean). The lower temporal variation was associated with periods of clear sky and relatively constant wind speed. It must be emphasized, however, that these variability assessments are based on measurements made out in the open, and therefore do not address local wind and sun shadow effects which substantially affect the WBGT index in and around tents and vehicles.

Beginning on 8 June, tank maneuvers in the vicinity of the 44th Evacuation Hospital required a consolidation of the deployed WBGT loggers to the central site. Nevertheless, based on the results for 7 June and the two previous days, it appears that the 1 km spatial, and 1 hr temporal variation in WBGT at that location were symmetrical and on the order ±1.0 °C.

4.2 SATELLITE-DERIVED HEAT STRESS ASSESSMENTS

4.2.1 *Performance of the Preliminary Algorithms*

Table 2 shows a comparison of the satellite-derived WBGT values with the nearest minute surface level measurements from the WBGT data loggers.

TABLE 2. COMPARISON OF SATELLITE-DERIVED WBGT WITH CONTEMPORARY SURFACE LEVEL MEASUREMENTS

Day	Time	Satellite/orbit#	Satellite WBGT	Measured WBGT	Difference
5 June	9:04	NOAA 10/8913	24.1°C	20.4°C	3.7°C
6	8:42	NOAA 10/8927	21.6	20.8	0.8
7	17:27	NOAA 9/17965	26.7	28.1	-1.4
8	9:39	NOAA 10/8956	24.3	23.9	0.4
	17:16	NOAA 9/17979	27.3	29.4	-2.1
9	9:17	NOAA 10/8970	26.1	26.4	-0.3
	17:05	NOAA 9/17993	27.6	29.8	-2.2
	20:34	NOAA 10/8977	24.0	25.7	-1.7
10	16:54	NOAA 9/18007	23.8	25.9	-2.1
11	16:42	NOAA 9/18021	22.8	25.2	-2.4
12	16:31	NOAA 9/18035	20.0	23.8	-3.8

For the eleven satellite passes in Table 2, the average difference between the satellite-derived and surface WBGT measurements was -1.0 °C and the standard deviation around that bias was ±2.1 °C. Work is in progress to identify those satellite-derived WBGT components responsible for the generally low estimates of WBGT at Fort Hood, and the necessary adjustments to the respective algorithms will be made. Nevertheless, in the context of the inherent uncertainty in the 'ground truth' measurements themselves (logger accuracy specification is ± 0.5 °C, spatial uniformity was ± 1.0 °C) performance of the preliminary algorithms is respectable and meets the accuracy requirements for this stage of the contract.

4.2.2 Significant Issues in Further Development

The most significant issue in further development of this capability is to enhance the accuracy of the satellite-derived heat stress in a way that does not overburden existing computational limits. To be of practical use in military training or operational settings, the capability for near-real-time assessments is essential. As we move from a single pixel heat stress image to one that may consist of hundreds or thousands of pixel elements, computation time may become a limiting factor.

Another important concern is the present limitation in the frequency of satellite passes. The current NOAA satellites leave a substantial data gap in the important mid-day portion of the diurnal cycle. While it may be possible to develop serviceable forecast models to make heat stress projections from a morning pass and other weather information, there would be substantial computational overhead. Additional NOAA or military satellites may alleviate this problem in the future.

5. SUMMARY

The potential for epidemic levels of heat injury in hot weather military operations is real. Heat injury is preventable if the heat stress can be quantified and appropriate counter measures are implemented. The utilization of meteorlogical data resources to support this preventive medicine issue is an essential part of the tactical weather intelligence picture in hot regions. The exploitation of satellite remote sensing technology holds great promise in terms of broad geographic area coverage and the capability for heat stress assessments beyond the forward line of troops (FLOT).

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